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SHORT RESEARCH COMMUNICATION

Characteristics of the event mean concentration (EMCs) from rainfall runoff on mixed agricultural land use in the shoreline zone of the Yamuna River in Delhi, India

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Abstract This paper is focused on the monitoring of the diffuse pollution characteristics from the agricultural land confining the River Yamuna in Delhi (capital of India). Agricultural fields surrounding the Yamuna river are direct nonpoint source of pollution impacting the river quality. The study includes watershed delineation for the River Yamuna using SWAT (2005) and land use classification for the city using GIS and remote sensing. Thereafter, the rainfall-runoff pollutant concentrations from the mixed agricultural land use were assessed for the 2006 and 2007 monsoon period (July–September). Runoff was measured using SCS method and grab samples of rainfall runoff were collected at three stations namely Old Delhi Railway Bridge (ODRB), Nizamuddin and Okhla bridge in Delhi. The samples were analysed for physico-chemical and biological parameters. Rainfall runoff and event mean concentrations (EMCs) for different water quality parameters were characterized and the effect of land use was analyzed. The average EMCs for BOD, COD, ammonia, nitrate, TKN, hardness, TDS, TSS, chlorides, sulfates, phosphate, fluorides and TC were 21.82 mg/L, 73.48 mg/L, 72.68 μg/L, 229.87 μg/L, 15.32 μg/L, 11.36 mg/L, 117.44 mg/L, 77.60 mg/L, 117.64 mg/L, 135.82 mg/L, 0.08 mg/L, 0.85 mg/L and 2,827.47 MPN/100 mL, respectively. The EMCs of TSS, nitrogen and its compounds, phosphate and BOD were high.

Keywords Watershed · Land use · Digital elevation model · Diffuse pollution · Surface runoff

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Introduction

Agriculture rainfall runoff is characterized as a nonpoint or diffuse source of water pollution. The pollutants in agricultural runoff may enter from both groundwater and surface water without passing through any treatment plants (Vaze and Chiew 2004; Crabtree et al. 2006; Terzakis et al. 2008). The common water contaminants from the diffuse sources can be grouped into various categories such as: sediments (TSS, TDS etc.); oil and toxic chemicals from automobiles (total petroleum hydrocarbons); nutrients from forest, animal and human activities (nitrogenous and phosphorus compounds like pesticides and biocides); heavy metals (As, Cu, Cd, Ni, Pb and Zn) (International Joint Commission 1974; Zoppou 2001; Ukabiala et al. 2010). The most common pollutants among the mentioned list are sediments and nutrients. These pollutants are washed off of agricultural fields and carried to streams, rivers, lakes and bays during rainstorms.

The economic viability of a river is threatened by its pollution which negatively impacts its users. In addition, it reduces the aesthetic value of the river. The pollutants released from various activities performed in domestic, industrial and agriculture sectors are discharged into rivers bringing about changes in the physical, chemical and biological characteristics of the river resulting in the depletion of dissolved oxygen (DO) and thus increasing deposition of organics, pathogens and nutrients in the water body (Kannel et al. 2011; Van der Velde et al. 2006; Cox 2003). The total event rainfall, antecedent dry period, cumulative seasonal rainfall and drainage area impact the quantity and quality of rainfall runoff prior to any treatment. Chui et al. (1982) and Tsihrintzis and Hamid (1997) studied the impact of the rainfall intensity and runoff volume upon the washed-off rate, and the dilution effects of accumulated contaminants, and their transportation to the receiving waters. The pollutants from storm are generated and transported in a diffuse manner with land use being one of the most important factors affecting the extent of pollution (Mallin et al. 2000; Lee et al. 2002; Tong and Chen 2002; Ackerman and Schiff 2003; Graves et al. 2004; Kim et al. 2005, 2007a, b; Yusop et al. 2005; McLeod et al. 2006; Zhao et al. 2007; Misra 2011). Candela et al. (2009) and Freni et al. (2010) concluded that both point and nonpoint sources cannot be neglected in water quality management.

Monitoring and estimation of diffuse pollution from the rainfall runoff is difficult in urbanized catchments with mixed land use pattern, since they are heterogeneous in nature and have anthropological interference. Over the years, several studies have been carried out to study the impact of point sources pollution on River Yamuna in Delhi (Bhargava 1983, 1986; Kazmi and Hansen 1997; Kazmi and Agarwal 2005; Paliwal et al. 2007; Sharma and Singh 2009; Parmar and Keshari 2011). Jamwal et al. (2008) estimated the diffuse pollution in urban areas of Delhi for the first time and stated that rainfall runoff from the agricultural area directly enters the river and from urban area reaches the river via wastewater drains, adding more pollutant loading. In this view, the present study was undertaken to monitor, characterize and estimate the pollutant concentration occurring due to rainfall runoff from the mixed agricultural land use (MAL) type. This MAL acts as a direct source of diffuse pollution to the River Yamuna in Delhi as it surrounds the banks of the river.

The study was carried out with following objectives: (1) land use classification of Delhi; (2) watershed delineation for area of interest (AOI); (3) calculating rainfall runoff from the watershed; (4) estimating the event mean concentrations (EMC) of runoff flows from MAL; and (5) analyzing relationships between EMCs and rainfall-runoff characteristics.

Description of study area

The River Yamuna is a major Himalayan river originating from Yamunotri glacier (6,096 m above sea level) descending from Mount Kalindi and forming into a regular river from Yamunotri onwards. Its main tributaries are Hindon, Chambal, Betwa, Sind and Ken. It covers the following states: Himachal Pradesh, Uttar Pradesh, Uttarakhand, Haryana, Delhi, Rajasthan and Madhya Pradesh. Delhi is a mega metropolis situated on the banks of the River Yamuna with an area of 1,483 km^2 (0.4% of total catchment) with a current population of approximately 17.6 million (http://www.indiastat.com). It enters from Palla traverses through the city and leaves it at Jaitpur near Okhla barrage (CPCB 2007).

Delhi has higher proportion of impervious area and sparse green area. In 2001, the annual drinking water requirement for the entire National Capital Region (NCR) was estimated as 2,310.07 million cubic meters (MCM) and the projections for the year 2021 are 4,374.27 MCM/annum (NCRPB Report, n.a.). In 2001, the annual estimated water availability in Delhi from different surface water sources was 1,150.2 MCM. However, according to an MOU signed in 1994, the River Yamuna will provide 724 MCM of water to Delhi annually (Planning Commission, n.a), approximately 70%, of Delhi's water requirements (Jain 2009). The total area of river zone is about 9,700 Ha, with approximately 1,600 Ha of land is under water and 8,100 Ha is dry land (Delhi Master Plan 2021). This dry land consists of MAL pattern and is a direct source of rainfall runoff to the river resulting in the augmentation of diffuse pollution levels into the river (Jamwal et al. 2008).

The Government of India (GoI) initiated the Yamuna Action Plan (YAP) in 1993 and later extended to YAPII in 2004 (CPCB 2007) to restore the river quality http://envfor.nic.in/nrcd/NRCD/YAP.htm. The class assigned to the River Yamuna in Delhi is 'C', meaning 'direct consumption of river water without any conventional treatment is not safe for health'. Table 1 provides a comparison of the river quality in Delhi over the past 15 years, which shows that even after completion of YAP I and II the water quality of the river does not meet the required standards. The main causes of surface water pollution in Delhi are higher population density per square kilometer on the riverbanks, poor sanitation practices by residents, untreated domestic wastewater, untreated industrial effluents, diffuse pollution, agricultural runoffs, dead body dumping, cattle washing etc. However, while designing YAP, diffuse pollution arising from open defecation, crematoria and religious activities were addressed and no emphasis was given to the pollutant loading directly from MAL neighboring the riverbanks. In order to enact further on improving the river water quality, it is also important to estimate the EMCs of pollutants directly entering the River Yamuna from the shoreline. This would help environment modelers to critically address the issue of diffuse pollution and will also lend a hand in designing the pollution abatement schemes.

Methodology

The study was done for a period of 2 years, 2006 and 2007, for three monitoring stations. Samples were collected with spatial variation and no temporal variation. Time critical data measurements and laboratory analyses were performed immediately or at most within 12 h of collection, since most water quality parameters are time dependent. The samples were stored and refrigerated at 5°C. Figure 1 illustrates the steps of methodology used for the study.

Land use classification and watershed delineation

The land use map was prepared using the IRS 1C-LISS-III imagery of 2006 using Supervised image classification method in ERDAS Imagine 9.0. On the basis of land use classification developed by NRSA (1995), the land use for Delhi was divided into five main classes namely water body; built-up area; forest; agricultural fields (sparse vegetation); and wasteland. Built-up area was further divided into high, medium and low dense urbanization. Thereafter, the watershed was delineated using Soil Water Assessment Tool (SWAT) 2005 model (Neitsch et al. 2005). The basic input data to SWAT included the digital elevation model (DEM), which was obtained from SRTM 90m Digital Elevation Data http://srtm.csi.cgiar.org/ and the land use classified above. The AOI consist of the watershed which was delineated for 0.2 km adjacent to the riverbanks where runoff directly enters the river during monsoon season.

Diffuse pollution assessment

In order to estimate the EMCs from the land use, the samples from three locations namely ODRB, Nizamuddin and Okhla were collected for 5 days (rainy days between July and September) from agricultural runoff sites using 'grab sampling method'. Three set of samples were analyzed for pH, BOD, COD, DO, ammonia, phosphate, hardness, TKN, TDS, TSS, nitrates and total coliforms using standard methods (Standard Methods, APHA 1998). The average concentrations from all the sites were used to calculate the EMCs using the formula:EMC = Mass of pollutant transported during the event/Total flow during the event.

$$\mathrm{EMC} = \frac{\sum Q_i C_i}{\sum Q_i}$$

where Q = discharge (m^3/s) and C = concentration (mg/L).

Hydrological data was obtained for each event from which includes antecedent dry day, event rainfall, runoff duration, rainfall intensity and runoff rate. The runoff was measured using Soil Conservation Service (SCS) curve number method (1964) and the meteorological data was

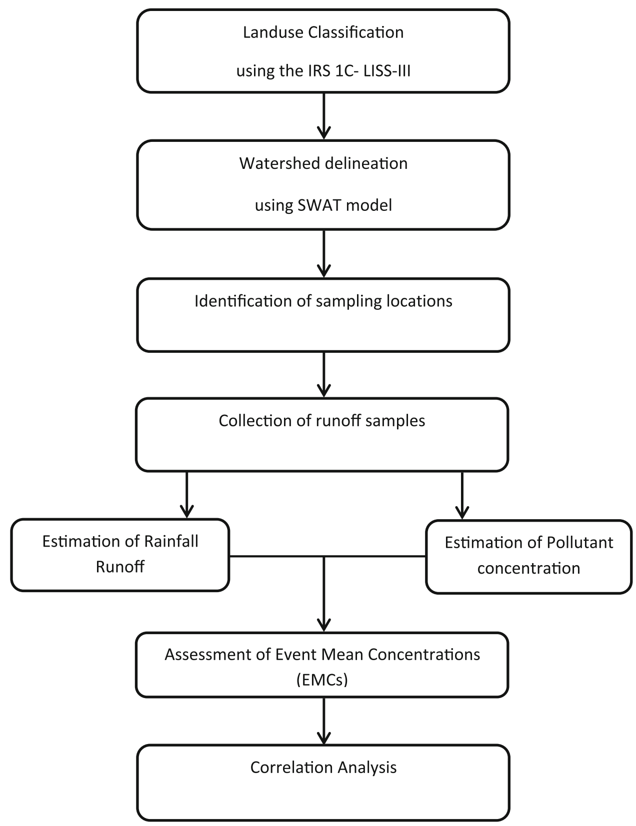

Fig. 1 Methodology flowchart

Table 1 Water quality of River Yamuna at Nizamuddin, Delhi, India

1995			2005			2009[a]		
DO	BOD	Total coliforms	DO	BOD	Total coliforms	DO	BOD	Total coliforms
3.4	9.6	386,091	1.6	10.00	12,200,000	0.0	23.00	22,516,660

The values for 1995 and 2005 have been taken from the Central Pollution Control Board (CPCB), Central Water Commission (CWC); Sources: CPCB 2000; CPCB 2007

[a] Units: DO and BOD: mg/L and TC: MPN/100 mL

obtained from Indian Meteorological Department (IMD) (Personal Communication). The soil composition of top layer is mainly 'sand type' (National Bureau of Soil Survey & Land Use Planning and Soni et al. 2009).

Results and discussion

The land use classification (Fig. 2) showed that in 2006, 67% of city was urbanized (99,361 Ha) with only 26% (38,558 Ha) of the green area, which is either located near the riverbanks or at the outskirts of the city. The total river area under water is 1600 Ha and the rest is wasteland which was 9,015 Ha. The land use pattern showed dense urbanization at the center of the city with only a few scattered patch of green area. Thereafter, DEM (Fig. 3a) was used to delineate the watershed which showed that the total area of watershed is 5,200 Ha (dry land) along the riverbed side (Fig. 3b) and comprises mainly MAL with very few urban settlements. Out of the total watershed area, 1,040 Ha of the catchment directly contributes to the diffuse pollution loading to the river. Therefore, only this watershed region was used to collect, characterize and estimate the rainfall-runoff pollutant concentrations. The three sampling locations were situated on the agricultural field adjacent to the river (Fig. 3b). Total ten rainfall events were selected to monitor the flow and runoff in the MAL (Table 2). The amount and intensity of the rainfall from MAL during the experiments were varied from 5 to 103.3 mm and from 1.11 to 41.32 mm/hr, respectively. Table 2 presents the hydrological data used consisting of rainfall characteristics and the runoff discharge calculated using SCS method.

The summary of descriptive statistical data of water quality concentrations measured at the three different locations done at 95% confidence level for mean is presented in Table 3. The mean ratio of COD to BOD was approximately 3.4. The level of organic pollutant concentrations was found to be higher than expected levels. The maximum range was observed for TC = 5,399 MPN/100 mL followed by TSS = 155.4 mg/L and minimum for hardness = 5.9 mg/L. The concentration of suspended solids found in river samples is 77.6 mg/L, which is an indicator of soil erosion from the watershed. The concentration for other parameters ammonia, nitrates, TKN and phosphates were found as 72.68 µg/L; 229.87 µg/L; 15.32 µg/L; and 0.8 mg/L respectively.

The estimated EMC of the pollutants from the MAL are presented in Table 4. The EMCs of BOD, COD, TDS, TSS

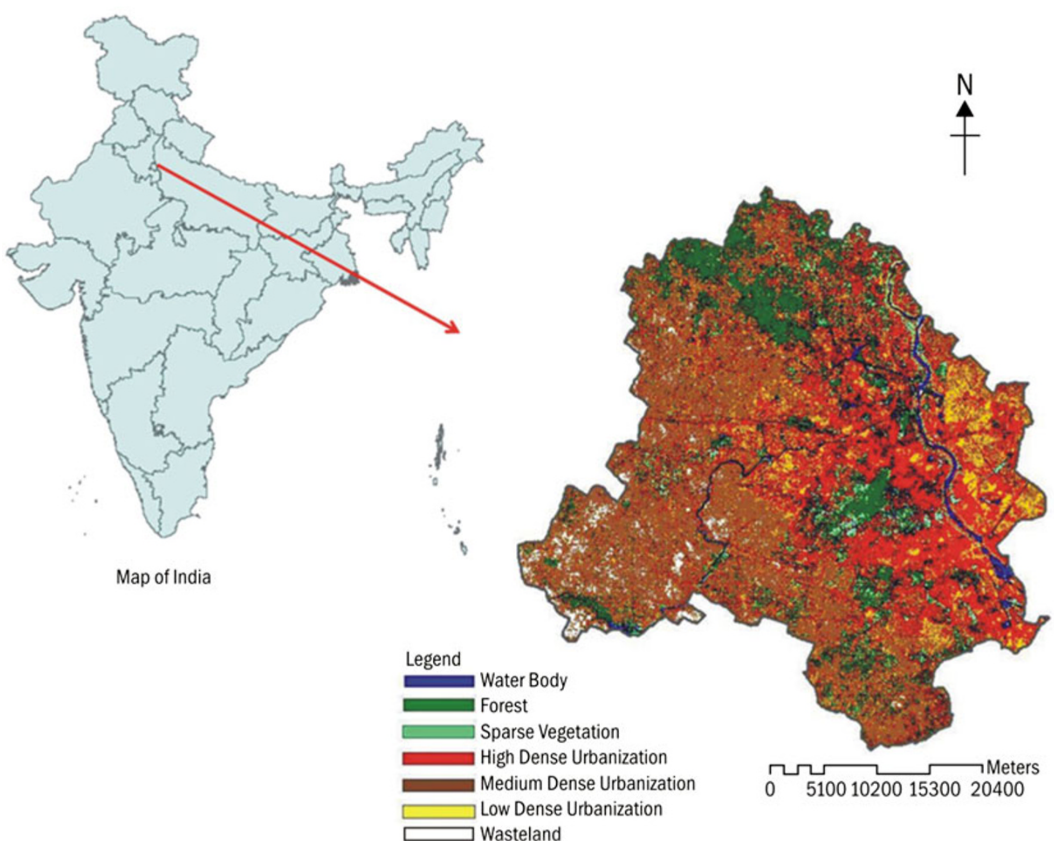

Fig. 2 Land use pattern in Delhi (2006)

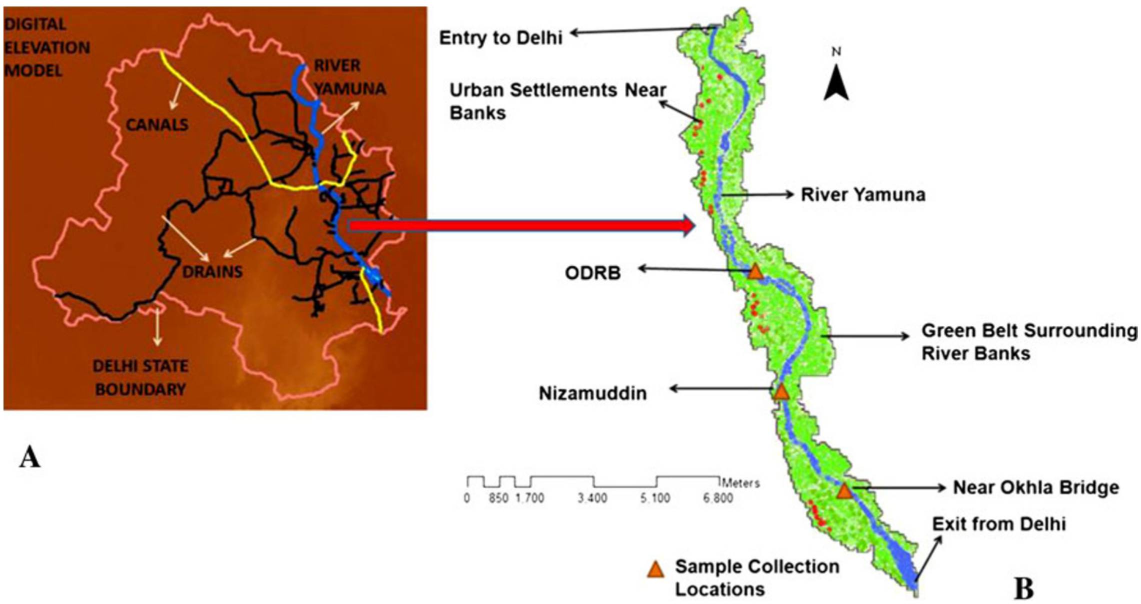

Fig. 3 Description of study area. **a** Digital elevation model with state boundary, River Yamuna, canals and drains (DEM is taken from SRTM 90m data); **b** Watershed of River Yamuna (Delhi) with sampling locations on MAL (prepared in SWAT with 0.2 km of MAL on both banks of river)

Table 2 Rainfall characteristics and runoff discharge

Date	Rainfall (mm)	Time (h)	Rainfall intensity (mm/h)	Total runoff (m^3)	Rainfall runoff (m^3/s)
2006					
12/07/2006	66.6	2.5	26.64	37.93	0.004214
27/07/2006	103.3	2.5	41.32	146.15	0.01624
01/08/2006	9.9	3.1	3.19	0.075	6.76E−06
30/08/2006	58.6	6.8	8.61	16.33	0.000667
03/09/2006	30.3	1.5	20.2	3.21	0.000594
2007					
14/07/2007	15	3.4	4.41	0.065	5.28E−06
24/07/2007	28	2.5	11.2	2.50	0.000277
2/08/2007	18	2.1	8.57	0.59	7.79E−05
19/08/2007	5	4.3	1.16	0.00007	4.63E−09
2/09/2007	5	4.5	1.11	0.00007	4.42E−09

and nitrogenous compounds showed higher values than expected. The mean of nitrogenous compounds are quite high with nitrates and TKN ranging from 211.35 to 243.35 and from 11.34 to 19.54 µg/L, respectively.

Table 5 shows Pearson correlation coefficients between EMCs and rainfall-runoff characteristics. Correlation significant at $p < 0.05$ are expressed in bold. COD, ammonia, hardness, TDS, TSS, sulfates, fluorides and TC are strongly related to rainfall intensity. COD, hardness and fluorides tend to decrease with increase rainfall, rainfall intensity and rainfall runoff. The assimilative capacity of a freshwater system increases with an increase in rainfall resulting in dissolution of inorganic salts. The positive correlation of rainfall intensity with TC concentration can be attributed to the availability of optimal conditions, i.e., moisture, temperature and nutrients which enhances the microbial activity. High correlation among TSS, rainfall, rainfall intensity and runoff clearly indicates that the runoff consists of suspended solids discharged from the MAL. Sulfides are also found to be positively correlated with the rainfall intensity and rainfall runoff. Most of the minerals are found positively correlated with rainfall runoff; this is due to the runoff fertilizers and manure from the surrounding agriculture fields.

It was observed that even during high rains only small amount of the total discharge is part of the runoff

Table 3 Descriptive statistics of rainfall runoff water quality from MAL

	BOD (mg/L)	COD (mg/L)	Ammonia (μg/L)	Nitrate (μg/L)	TKN (μg/L)	Hardness (mg/L)	TDS (mg/L)	TSS (mg/L)	Chlorides (mg/L)	Sulfates (mg/L)	Phosphate (mg/L)	Fluorides (mg/L)	TC (MPN/100 mL)
Mean	21.82	73.48	72.68	229.87	15.32	11.36	117.44	77.60	117.64	135.82	0.08	0.85	2,827.47
Standard error	0.80	3.44	2.35	2.05	0.60	0.27	2.45	8.05	2.26	7.38	0.00	0.03	313.20
Median	21.30	77.52	76.45	233.08	15.04	10.98	119.24	61.20	120.37	123.01	0.08	0.87	2,117.00
Standard deviation	4.36	18.86	12.87	11.23	3.26	1.49	13.43	44.10	12.38	40.43	0.01	0.14	1,715.46
Range	15.42	70.08	41.36	35.06	11.26	5.90	46.06	155.44	38.06	128.56	0.03	0.48	5,399.00
Minimum	15.08	34.08	46.48	209.89	9.88	9.24	87.68	44.30	95.68	83.58	0.06	0.62	1,179.00
Maximum	30.50	104.16	87.84	244.95	21.14	15.14	133.74	199.74	133.74	212.14	0.09	1.10	6,578.00
Count	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Confidence level (95.0%)	1.63	7.04	4.80	4.19	1.22	0.56	5.02	16.47	4.62	15.10	0.00	0.05	640.56

Table 4 Event wise descriptive statistical analysis of EMCs

Event	BOD (mg/L)	COD (mg/L)	Ammonia (μg/L)	Nitrate (μg/L)	TKN (μg/L)	Hardness (mg/L)	TDS (mg/L)	TSS (mg/L)	Chlorides (mg/L)	Sulfates (mg/L)	Phosphate (mg/L)	Fluorides (mg/L)	TC (MPN/100 mL)
1	25.59	35.55	85.14	238.31	17.68	10.70	120.14	100.14	120.14	210.54	0.08	0.88	6,534.67
2	21.86	67.69	86.24	234.68	12.44	11.01	123.14	198.14	119.14	184.84	0.08	0.80	5,472.00
3	19.59	84.74	84.24	231.35	13.54	11.04	118.14	51.93	102.14	113.94	0.07	0.95	2,300.67
4	17.56	49.38	67.64	226.64	18.84	11.74	132.14	87.14	130.14	124.34	0.09	0.82	1,232.67
5	22.36	85.84	76.54	211.35	15.74	11.01	129.14	67.50	129.14	94.64	0.08	0.70	3,245.00
6	23.73	83.55	54.44	243.35	12.24	11.12	130.14	55.40	119.14	101.54	0.07	0.98	2,100.67
7	16.63	71.35	47.94	223.24	18.54	11.12	117.14	61.58	97.14	172.64	0.07	1.00	1,865.67
8	19.56	69.55	76.64	243.24	11.34	11.00	98.14	58.03	102.14	85.04	0.07	0.72	1,381.00
9	21.26	102.55	66.64	234.74	19.54	13.54	89.14	45.10	125.14	121.54	0.08	1.03	1,987.67
10	30.06	84.65	81.34	211.84	13.34	11.34	117.14	51.00	132.14	149.14	0.09	0.69	2,154.67
Mean	21.82	73.48	72.68	229.87	15.32	11.36	117.44	77.60	117.64	135.82	0.08	0.85	2,827.47
Standard error	1.25	6.17	4.20	3.66	0.98	0.26	4.38	14.45	4.04	13.24	0.00	0.04	562.10
Median	21.56	77.45	76.59	233.01	14.64	11.08	119.14	59.81	119.64	122.94	0.08	0.85	2,127.67
Standard deviation	3.97	19.50	13.27	11.56	3.11	0.81	13.86	45.69	12.76	41.88	0.01	0.13	1,777.50
Range	13.43	67.00	38.30	32.00	8.20	2.84	43.00	153.04	35.00	125.50	0.02	0.34	5,302.00
Minimum	16.63	35.55	47.94	211.35	11.34	10.70	89.14	45.10	97.14	85.04	0.07	0.69	1,232.67
Maximum	30.06	102.55	86.24	243.35	19.54	13.54	132.14	198.14	132.14	210.54	0.09	1.03	6,534.67
Confidence level (95.0%)	2.84	13.95	9.49	8.27	2.22	0.58	9.91	32.68	9.13	29.96	0.01	0.09	1,271.55

(Table 2). However, it cannot be neglected since it directly enters the river body and may result in amplification of the pollutant loadings from the agricultural area to the river. The agricultural runoff contains high amount of BOD, COD, solids, nitrogen and its compounds and other ions, which indicates the process of erosion and also justifies that the area under study is MAL. The result also implicates the applicability of pesticides and insecticides resulting in pollutants consisting of nitrogenous and phosphorus compounds.

Conclusions

The study explored the characteristics of diffuse pollutant loads from MAL watershed, through flow monitoring and

Table 5 Correlation analysis of EMCs with rainfall characteristics

Water quality parameters	Rainfall (mm)	Time (h)	Rainfall intensity (mm/h)	Total runoff (m^3)	Rainfall runoff (m^3/s)
BOD (mg/L)	−0.10	−0.04	0.02	0.04	0.07
COD (mg/L)	**−0.68**	−0.09	−0.50	**−0.33**	**−0.29**
Ammonia (μg/L)	0.33	−0.16	0.41	0.43	**0.44**
Nitrate (μg/L)	0.15	−0.09	0.08	0.19	0.19
TKN (μg/L)	0.05	0.37	−0.09	−0.21	**−0.24**
Hardness (mg/L)	**−0.33**	0.50	−0.43	−0.22	**−0.23**
TDS (mg/L)	0.42	0.10	0.32	0.21	0.19
TSS (mg/L)	**0.94**	−0.14	**0.91**	**0.99**	**0.98**
Chlorides (mg/L)	0.14	0.47	0.06	0.09	0.07
Sulfates (mg/L)	**0.62**	−0.05	0.58	0.57	**0.56**
Phosphate (mg/L)	0.29	0.44	0.19	0.23	0.20
Fluorides (mg/L)	−0.18	0.11	−0.26	−0.16	−0.15
TC (MPN/100 mL)	**0.70**	−0.43	0.83	**0.68**	**0.70**

grab sampling of water from rainfall-runoff event were studied. The EMCs of diverse forms of organics, suspended solids, and nutrients were estimated. Field monitoring was conducted over ten storm events from 2006 to 2007 using manual sampling methods. EMC of individual runoff event was estimated for each water quality constituent based on the flow rate and concentration data of runoff discharge. The average EMCs of BOD, COD, ammonia, TKN, nitrate, hardness, TDS, TSS, chlorides, sulfates, phosphate, fluorides and TC of the MAL were 21.82 mg/L, 73.48 mg/L, 72.68 μg/L, 229.87 μg/L, 15.32 μg/L, 11.36 mg/L, 117.44 mg/L, 108.64 mg/L, 117.64 mg/L, 135.82 mg/L, 0.08 mg/L, 0.85 mg/L and 2,827 MPN/100 mL, respectively. The results showed a strong correlation of pollutant characteristics with rainfall intensity and total runoff flows. The results provide principal information for the management of NPS pollutants entering the river basin and would be helpful to perform diffuse pollution modeling studies to evaluate the pollutant loading to the river system.

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